School of Electronic Engineering and Computer Science

Cooperative and Low-Power Body Area Network: *Does it really mean better energy and power consumption?*

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**** The slides are self explanatory and for more details about the work please refer to the following publication by the authors:** Raffaele Di Bari, Akram Alomainy and Yang Hao, *"Cooperative and Low-Power Wireless Sensor Network for Efficient Body-Centric Communications in Healthcare Applications"*, Wireless Mobile Communication and Healthcare, Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering Volume 61, 2013, pp. 351-360

Queen Mary
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Talk Outline

- Introduction
- Cooperative Networking for BAN
- Effect on Link and Energy Efficiency
- Body-Centric Radio Propagation
  - Channel Characterisation
  - Statistical Modelling
- UWB System-Level Modelling for Low-Power Applications
- Summary

Introduction

- Most current wireless Body-Centric Networks solutions depend heavily on star network topology with limited means to overcome obstacles and/or body shadowing of propagating radio waves.
- Thus, for reliable communications an increase in power consumption is required, reducing battery life.
- This limitation can be overcome by networks with sensor cooperative capabilities such as information exchange between neighbour devices and data multi-hop routing among the nodes through the most efficient communication link.

Motivation

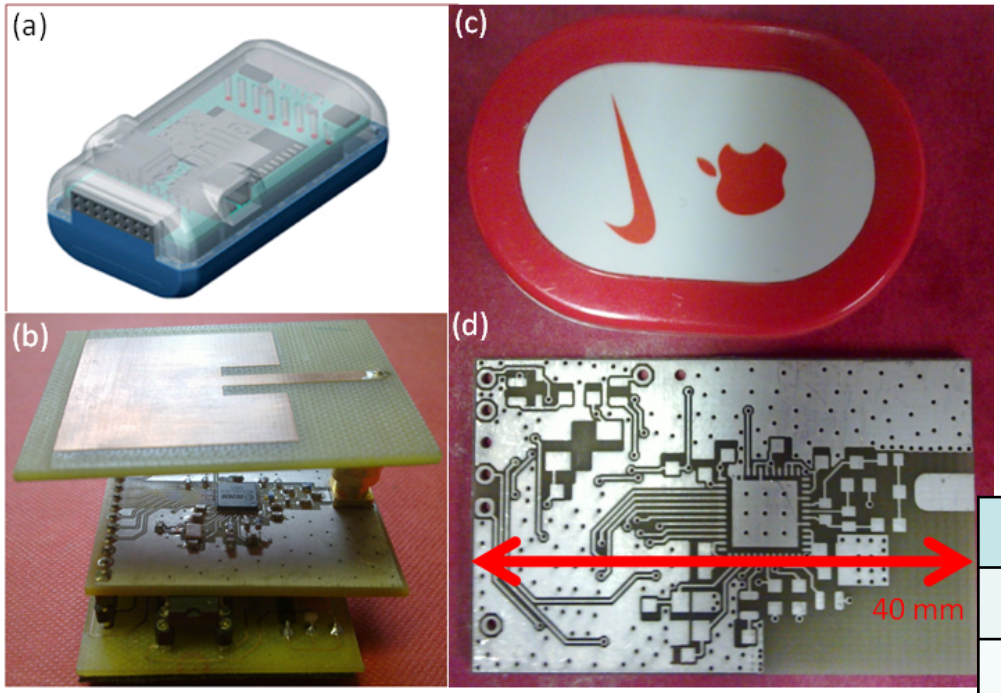
- Developing a cooperative Body-Centric Wireless Networks demonstrator for e-health applications.
- Maximize the minimum lifetime of the system and estimate the Network energy saving and
- Achieve various tasks in the cycle of antennas-radio channels-system performance-implementation.
- Comprehensive statistical channel modelling for body-centric wireless communications.
- Evaluation of system performance in various scenarios and providing recommendations.

Example Applications: BAN for ambulatory monitoring of physiological responses

Initial Test Settings

- A Sentilla Perk sensor kit has been chosen to set-up a cooperative Body-Centric Wireless Network at 2.4 GHz.
- The system is IEEE 802.15 standard-compliant.
- An power-efficient routing algorithm has been implemented on the top of the standard connection functionality provided by the Sentilla Motes kit.
- The routing algorithm seeks to achieve minimum cost forwarding, where costs are proportional to the path-loss.
- Moreover, it aims to provide implementation simplicity, data processing lightweight, and network scalability.

Wearable Units

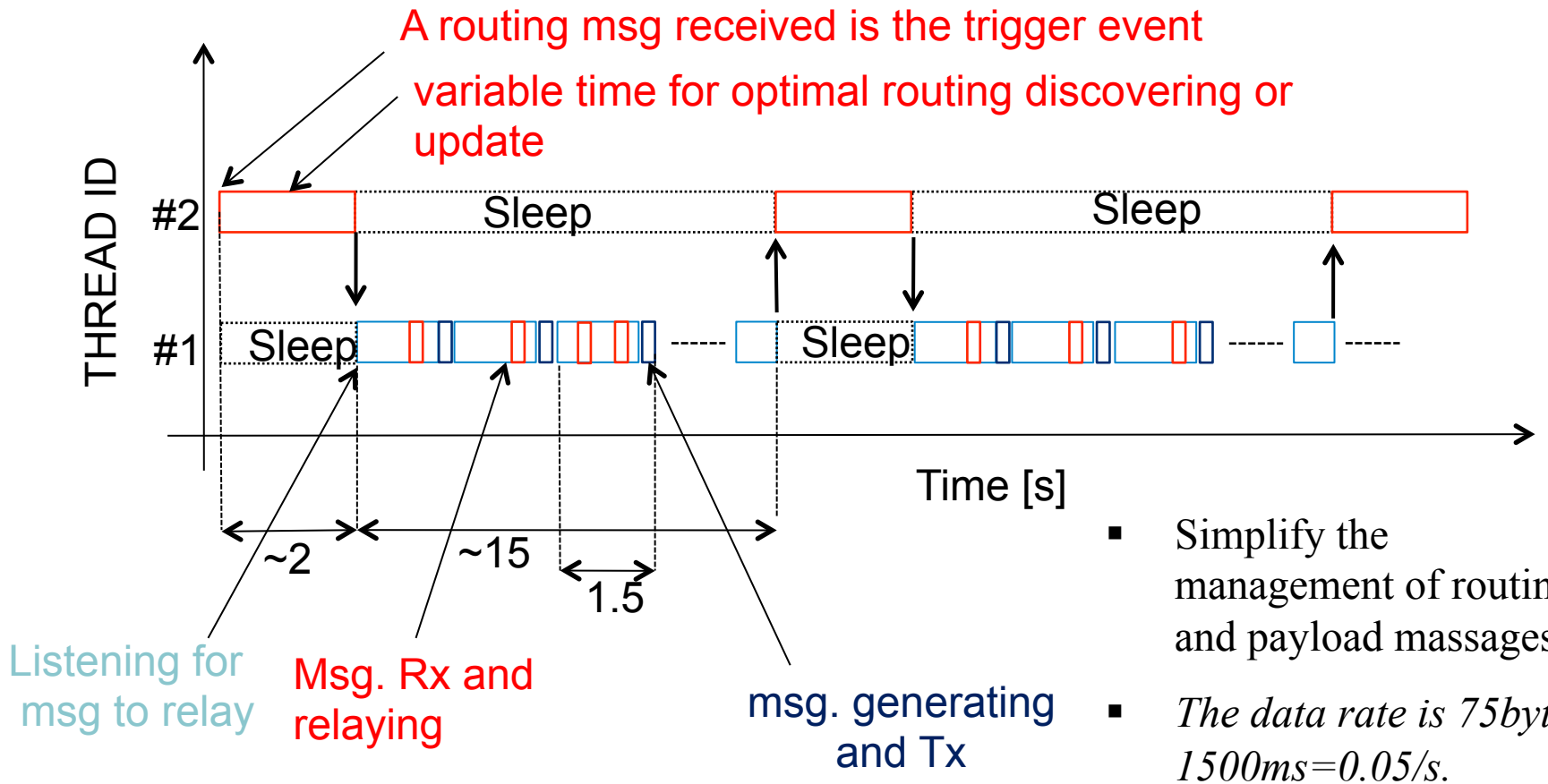


- A market available sensor kit has been used.
- Sensor prototype have been in-house built and ready to work.
- In-house system design allows to test different antennas

Capability	Sensor (Sentilla)
RAM (kB)	512
Flash (kB)	4096
Speed (MHz)	8
Active (mA)	4
Idle (mA)	1
Sleep (uA)	1
Architecture	16-bit

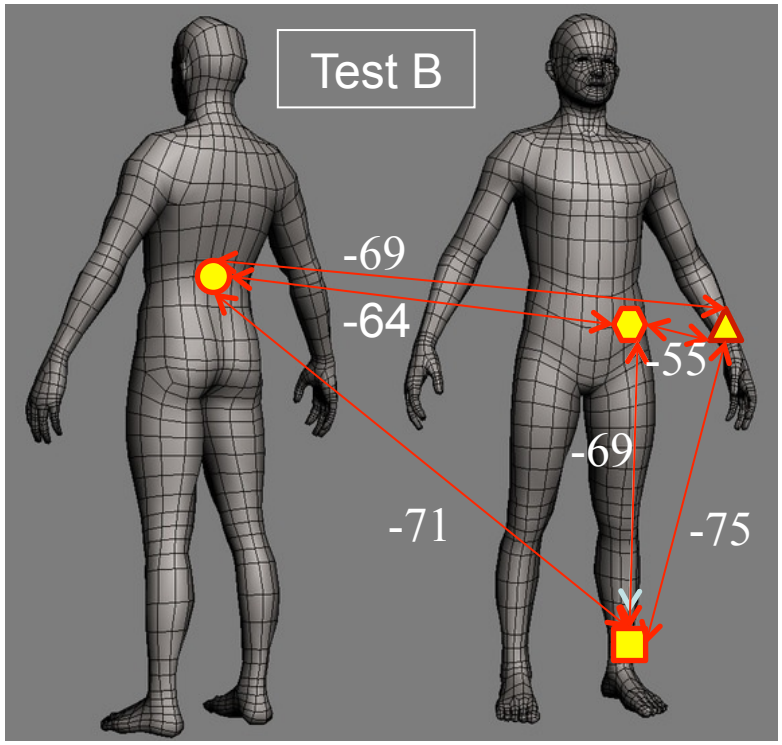
The table shows the Sentilla Motes hardware characteristics. The Motes embeds a CC2420 802.15.4 Radio, MSP430 microcontroller and several analogue sensors, including a 3-axial acceleration sensor.

Multi-Thread Implementation

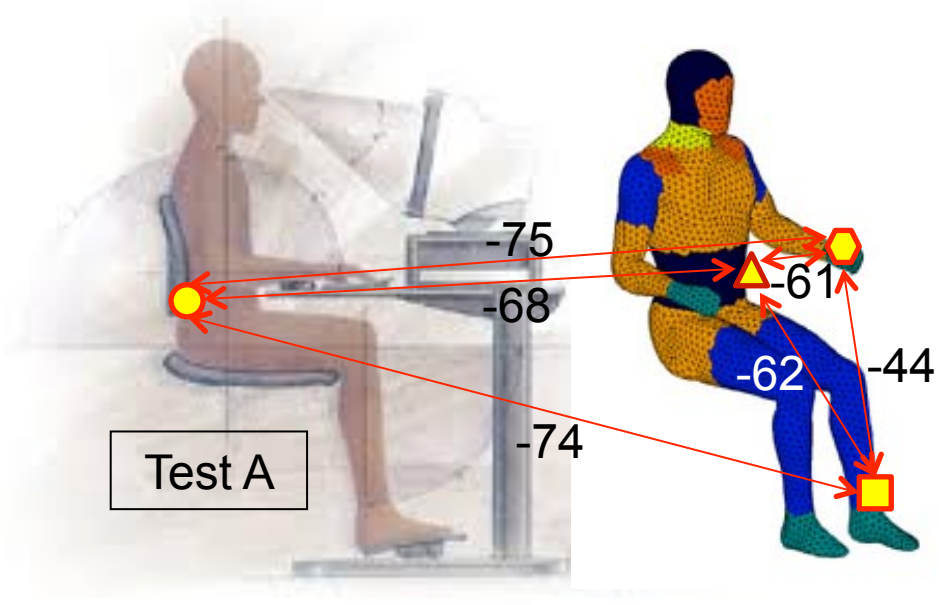


- Simplify the management of routing and payload massages.
- *The data rate is 75byte/ 1500ms=0.05/s.*

Measured Body-Centric Links

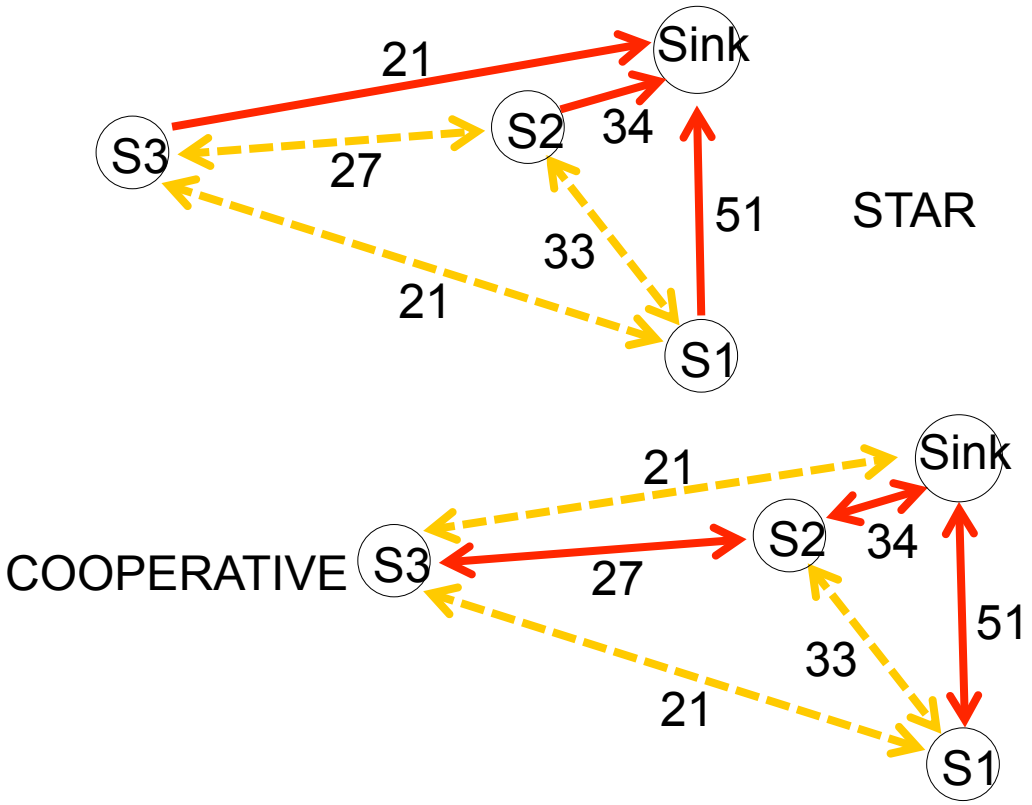


Symbol	Index
⬡	Sink
△	S1
□	S2
○	S3



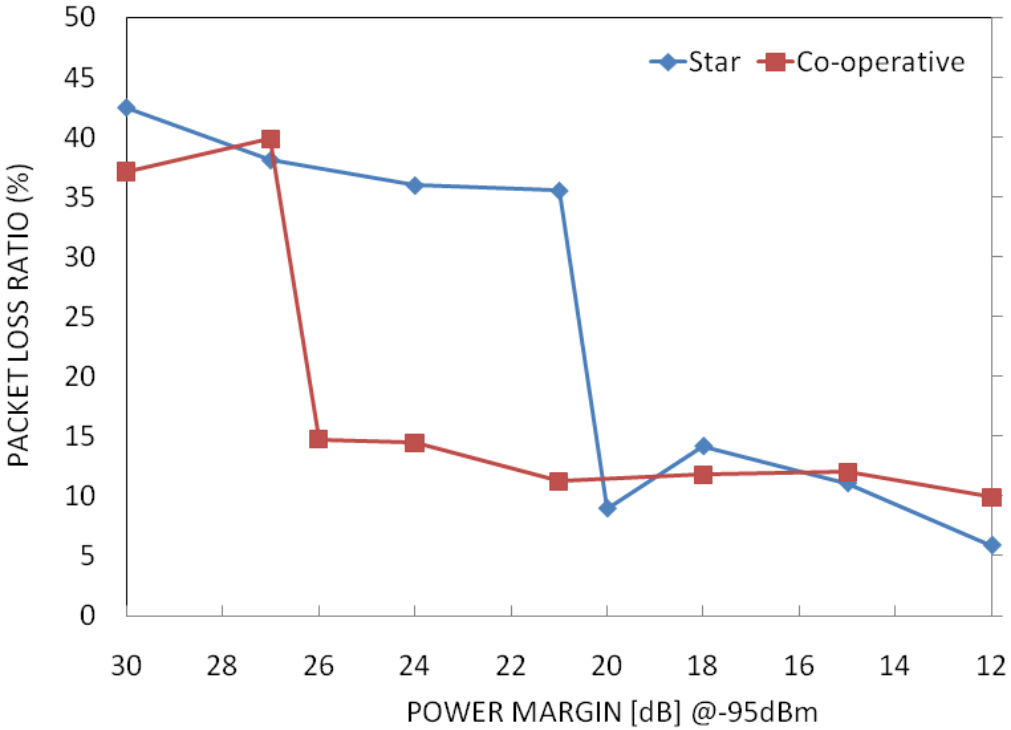
- A sample on-body real case scenario is selected for test evaluation. No movements were allowed.
- The transmitted power (expressed in dBm) is constant and equal to 0 dBm for all motes.

Topologies and Power Margins



- The Network Power Gain (NPG) can be related to the minimum power margins, estimated against the receiver threshold -95dbm.
- Minimum power margins are 20 dB and 26 dB for the star and cooperative topology, respectively.

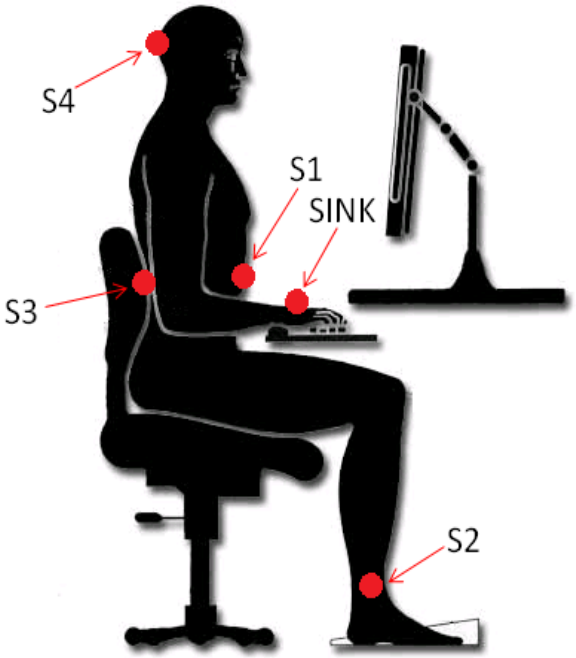
Initial Network Test results



Performances comparison of the two network topology.

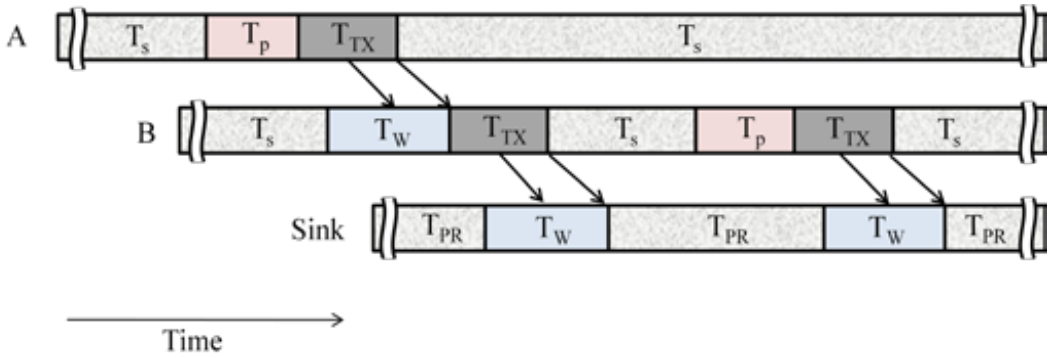
- These values can be translated as 6 dB NPG for the cooperative network.
- The NPG depends on the particular displacements scheme and the number of the sensors on the body.
- The cooperative routing processing overhead does not degrade the sensors performances.
- A Sensors synchronization can avoid the packet collision, eliminate the packet loss plateau, and increase the network reliability.

Modified System Set up

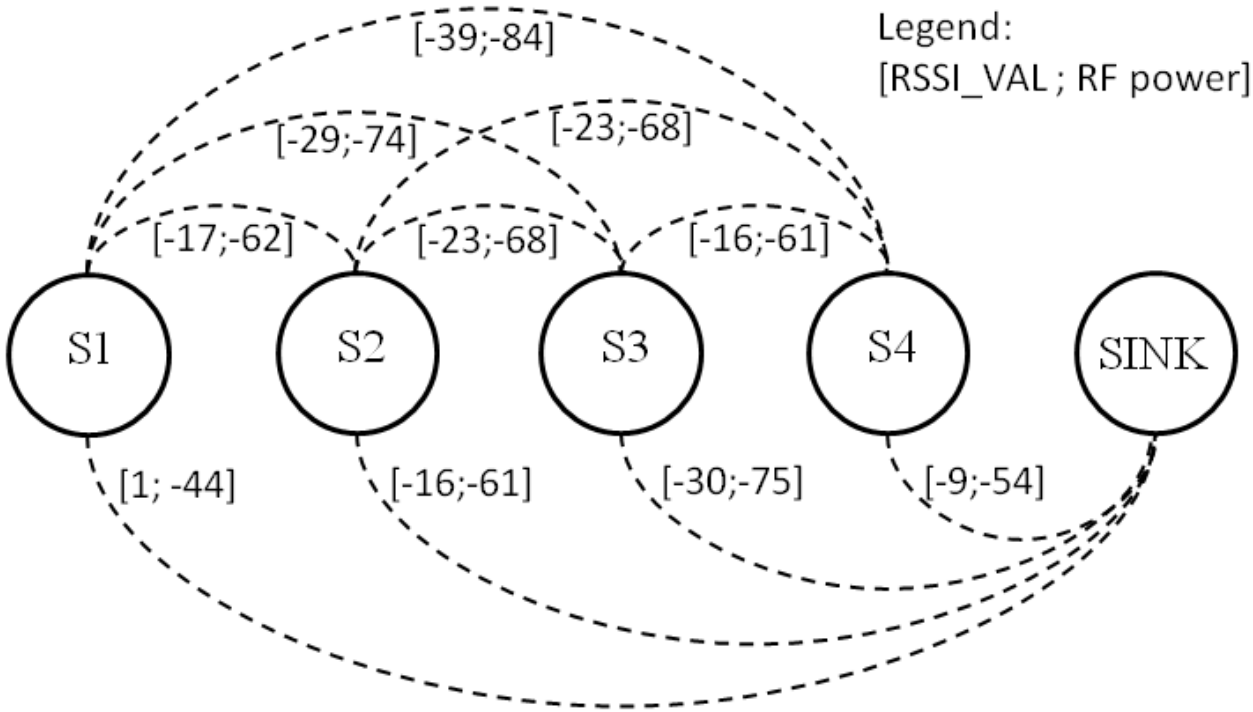


Displacement map of sensor sensors on volunteer body

Sentilla Mote used for this research. The Motes embeds:
-a CC2420 802.15.4 Radio,
-MSP430 microcontroller
-several analogue sensors, including a 3-axial acceleration sensor.



Network Topology Characterisation: Link Cost



Link Costs based on Averages RSSI /RF powers in dBm
for sitting postural set-up

Network Topology Characterisation: Link Cost

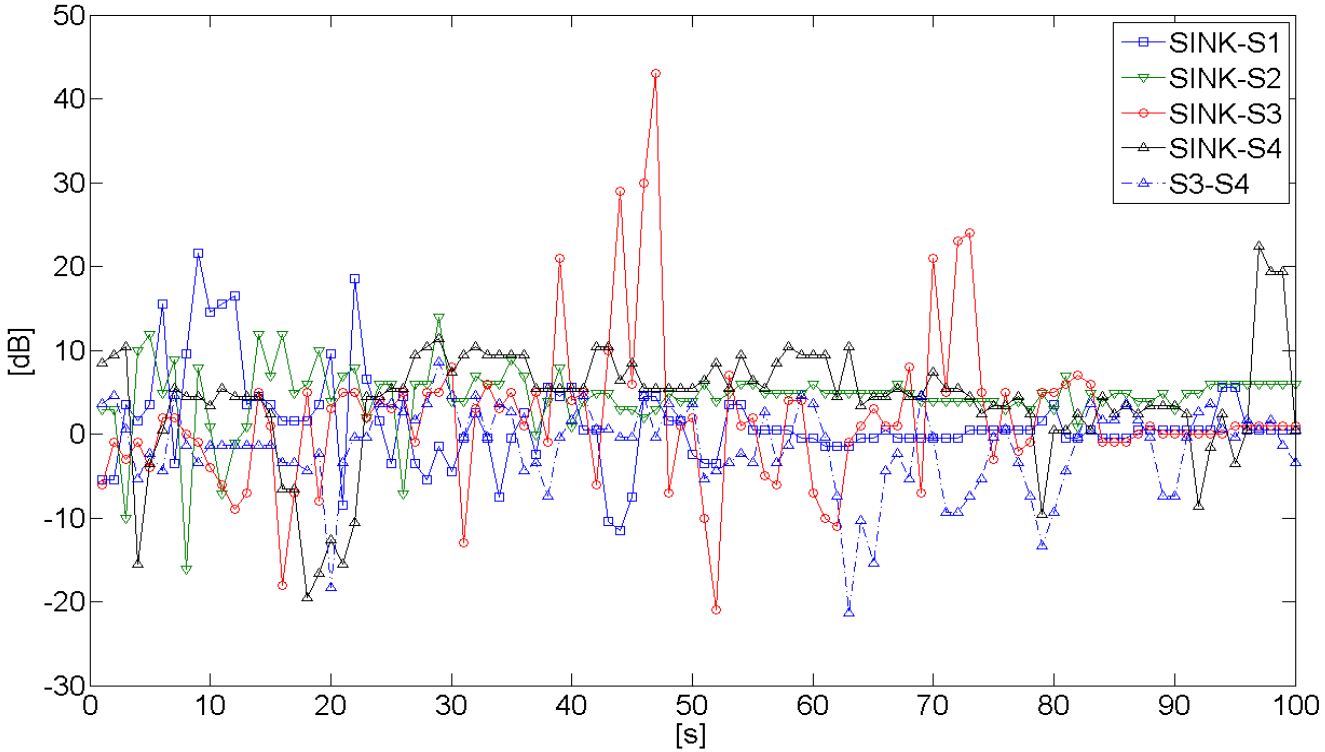
- Extra power margin Is needed to guarantee the RSSI to be above the sensitivity threshold during the observation time for a given probability (e.g. ≥99%)

- $M_0 = P^T_0 - S_R - L_P$
  - S_R is the sensitivity, L_P is the path loss, and P^T_0 is the maximum transmit power (e.g. ~0 dBm).

- $L_P = L_{AVG} + L_S$
  - L_{AVG} the value predicted by the average path loss model, and the shadowing component L_S is a zero-mean Gaussian random variable with standard deviation σ.

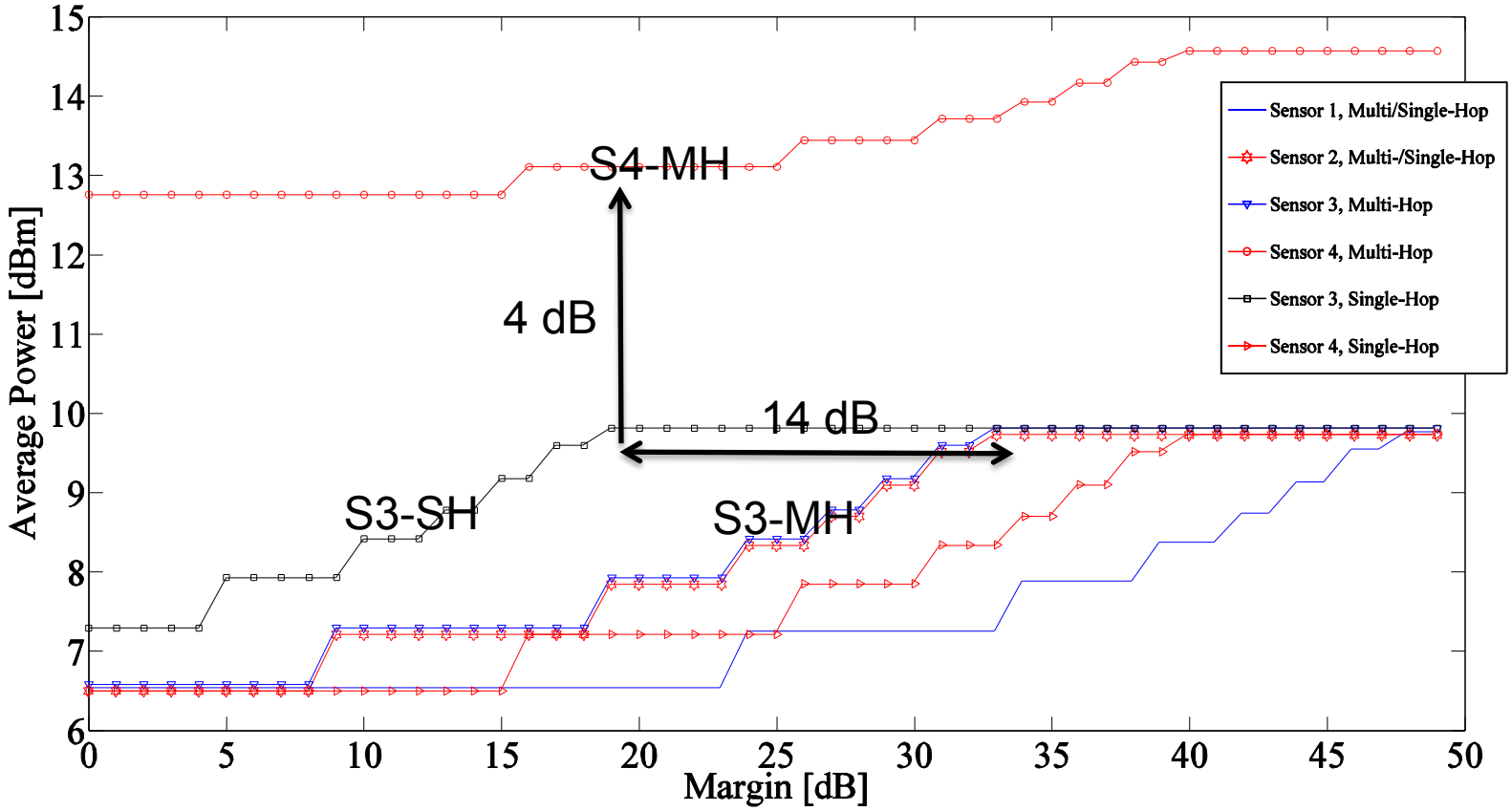
Link	L_{AVG}[dB]	M_0[dB]	L_S [dB]			
			σ	Range	Min.	Max.
γ_{S1}	-44	24	7.2	53	-31.4	21.52
γ_{S2}	-62	42	6.7	43	-25.11	17.89
γ_{S3}	-75	20	8.1	66	-23.02	42.98
γ_{S4}	-54	34	7.4	44	-21.57	22.43
γ_{34}	-61	41	5.0	32	-21.33	10.67

Network Topology Characterisation: Time Variability



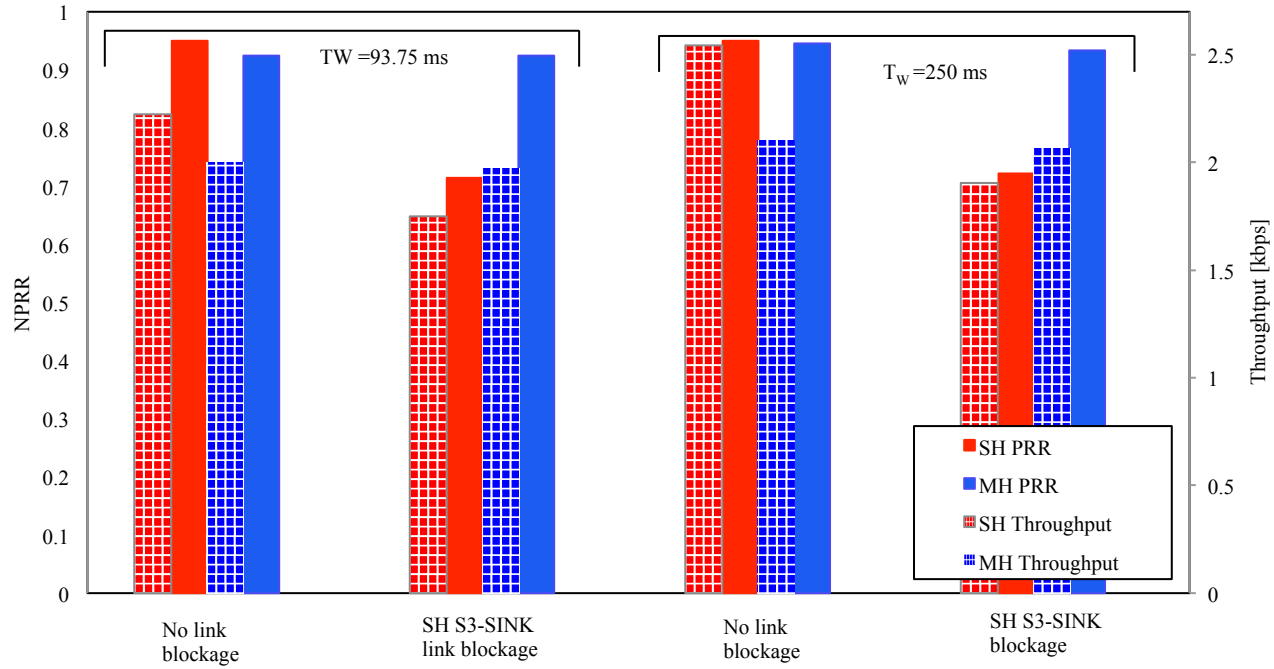
Sample L_S history during the first 100 measurement seconds with sampling rate of 1 second

Network Topology Characterisation: Power Consumption



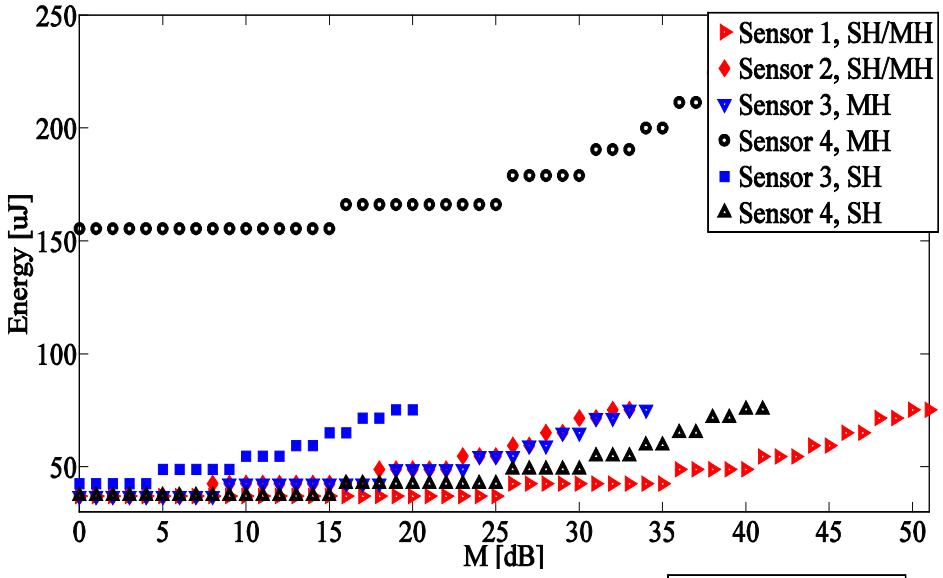
Average power consumption against margins for multi-hop (MH) and single-hop (SH)

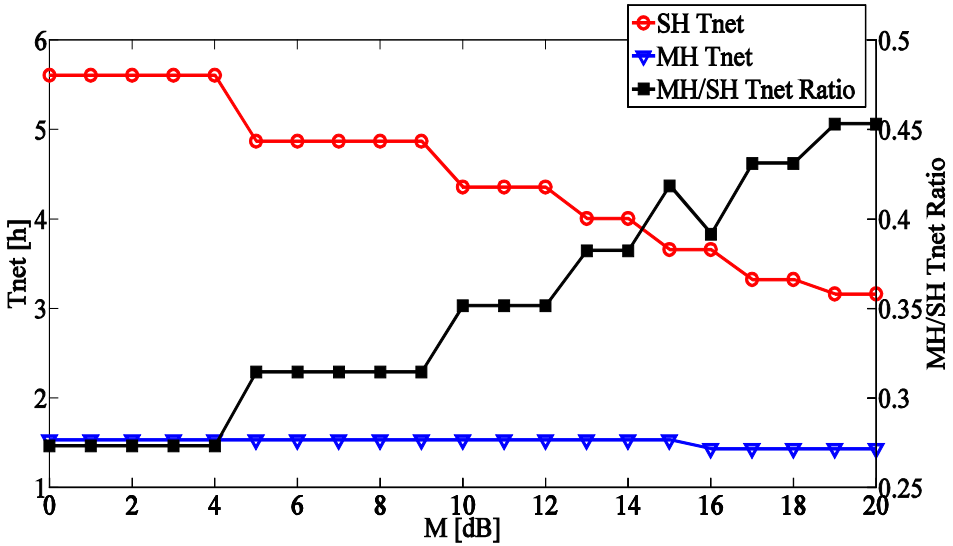
Network Packet Delivery Ratio



- The MH low throughput is due to the synchronization approach used.
- In case of S3-sink link blockage, the SH PDR degrades of about 23% compared to the MH with no link blockage for both T_w cases, while the SH throughput reduction is 21% and 25% for the T_w case of 93.75 ms and 250 ms, respectively.
- This means that the MH topology can be successfully used to overcome SH link blockages.

Network Lifetime: Single vs. Multi-Hop



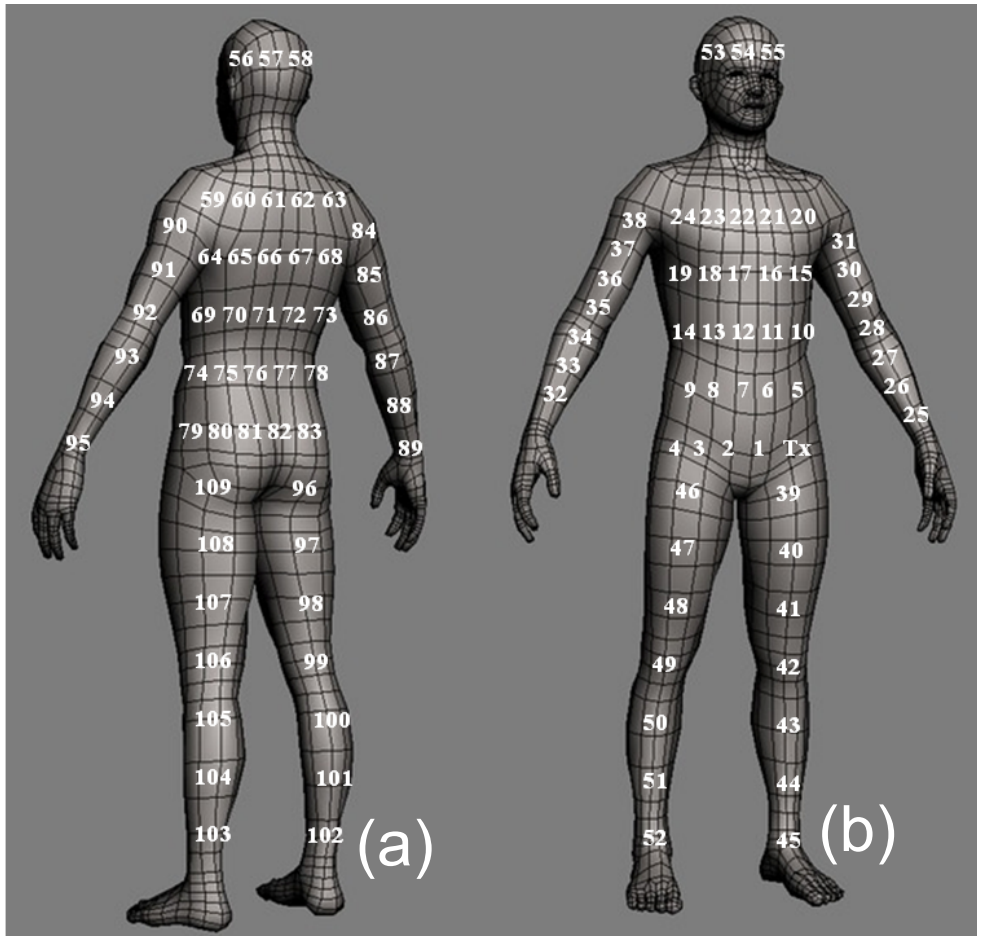


- Network lifetime of the MH network is reduced by 25% to 45% compared to SH.
- T_{net} corresponds to the lifetime of sensors S3 and S4 for SH and MH configurations

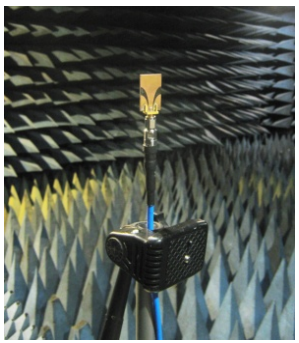
UWB BAN Statistical Channel Modelling

- Radio channel characteristion for UWB on-body and off-body channels based on frequency domain measurements.
- Deriving a stochastic channel model based on a large number of receivers regularly displaced all over the body.
- The statistical distribution of channel parameters is estimated by using jointly the Kolmogorov-Smirnov (KS) and Second Order Akaike (AICc) criteria.
- The additional information retrieved by this approach is compared to a standalone use of KS or AICc standalone criterion.

Channel Measurement Setting



Receiver Range	Reference
1-55	LOS
56-109	NLOS
1-109	Generic
1-24	Waist-to-chest



Channel Measurement Setting

Parameter	Values
Frequency Range	3-10 [GHz]
Sampling rate	1601 frequency points
Sweep Time	800 [msec]
Unambiguous Excess time Delay	228.8 [ns]
Max. Temporal resolution	142.8 [psec]
Tx. power	0 [dbm]
IF bandwidth	3KHz
DANL	-101 dbm
Antenna	Omni-directional Tapered Slot Antennas (TSA)
Receiver Locations	109

Frequency domain measurement settings

Data Pre-Processing

Parameter	Description/Values
Measurement tool	Agilent N5230C PNA-X
Frequency Transform	Baseband IFFT
Number of measurements per test location	2
Number of sweeps per measurement	16
First path detection algorithm	20 dB threshold
Time window for first path detection	0-3 [ns] (on-body)
	0-100 [ns] (off-body)
Normalization	To the first path of each channel impulse

Channel Test Results (KS and AIC)

KS criterion AND AICc TESTS PASSING RATE (%)

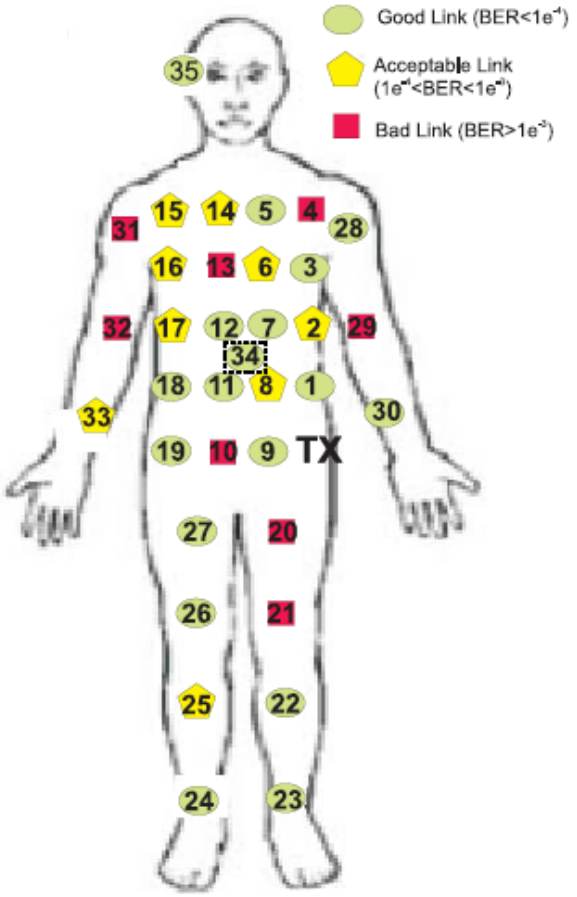
Scenario			KS criterion					AICc				
			N	R	W	N	L	N	R	W	N	L
on-body	chamber	LOS	38.9	5.2	100	72.7	100	0	0	18.1	0	81.8
		NLOS	17.2	14.9	100	70.1	100	0	6.8	11.4	3.4	78.1
		Generic	12.6	8.0	97.7	43.6	100	0	5.7	9.1	0	85.0
	indoor	LOS	24.8	36.6	98.8	87.5	100	0	15.8	36.2	2.8	45.2
		NLOS	25.6	42.3	100	77.6	100	0	32.7	2.8	0	64.4
		Generic	17.1	36.2	98.4	66.03	100	0	27.3	8.5	0.6	63.5
off-body	chamber	LOS	10.5	42.1	100	73.6	100	0	21.0	21.0	0	57.8
		NLOS	2.3	20	100	62.3	100	0	11.7	23.5	5.8	58.8
		Generic	6.3	33.3	100	63.9	100	0	21.6	21.6	4.5	52.2
	Indoor	LOS	18.5	43.7	100	77.0	100	0	32.6	8.9	0.7	57.7
		NLOS	6.15	34.2	100	67.6	100	0	19.2	16.6	0	64.1
		Generic	6.4	32.5	100	64.5	100	0	18.7	28	1.1	52.3

Performance vs. On-body Location

Various Energy-to-Noise ration to determine optimum Eb/No for low-power system

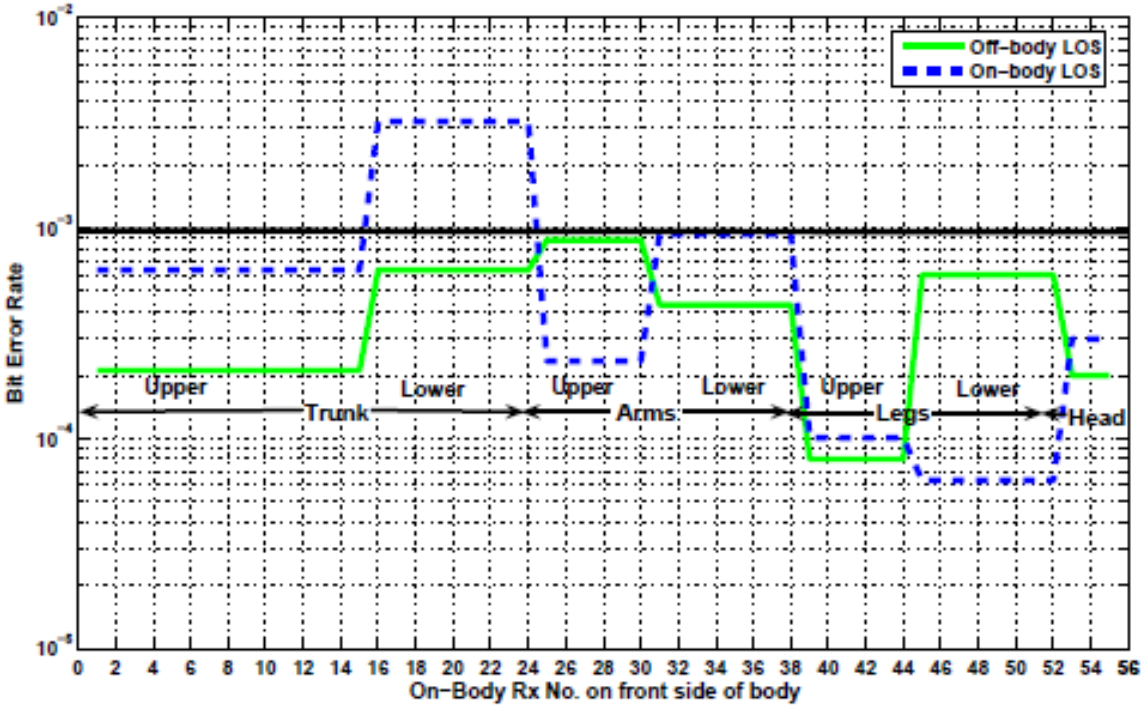
CHARACTERISATION OF THE ON-BODY RADIO LINK QUALITY FOR VARIOUS SECTORS OF THE HUMAN BODY (THE TORSO WHICH INCLUDES THE BACK, LEGS, ARMS AND THE HEAD) FOR BER THRESHOLD OF $1e^{-3}$ AT EB/NO = 4DB

Link Quality	Good	Acceptable	Bad
Torso	50.0	35.0	15.0
Arms	33.3	16.7	50.0
Legs	62.5	12.5	25.0
Head	100.0	-	-



Q. H. Abbasi, A. Sani, A. Alomainy and Y. Hao, "Radio Channel characterization and system-Level Modeling for Multiband OFDM Ultra Wideband Body-Centric wireless networks", IEEE Transactions on Microwave Theory and Techniques, Vol. 58, no. 12, pp. 3485-3492.

BER Results for all scenarios

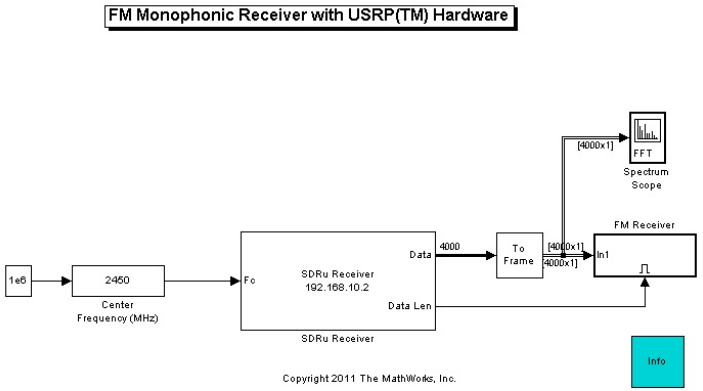


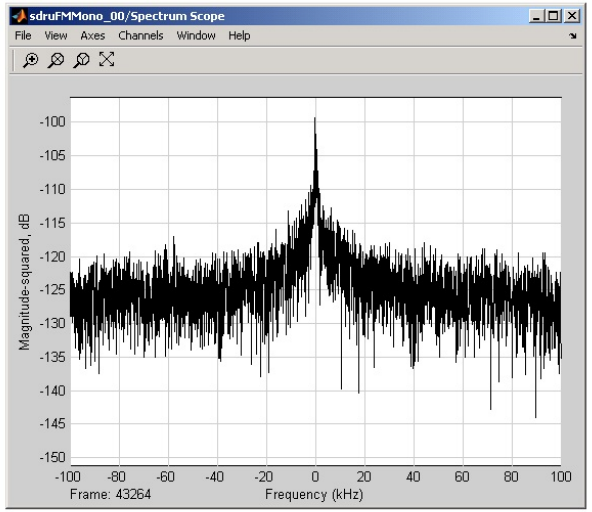
System outage percentage for different body parts at Eb/No= 4 dB

	On-Body		
Body Parts	Upper Part	Lower Part	Total
Trunk	26.66	52.63	38.77
Arms	8.33	28.57	19.23
Legs	8.33	0	3.57
Head	x	x	16.66

Next step: Real-Life Implementation

- Using software-defined radio development kit
  - Ettus Research Universal Software Radio Peripheral (USRP) Boards
- Testing of cooperative concept and channel sensing
- Reconfigurable antennas designed and fabricated by PhD student to be integrated with the test platform





Summary

- The cooperative scheme requires 6 dB less power to achieve the same performance as the non-cooperative scheme.
- For a acceptable packet delivery ratio, multi-hop (MH) scheme can provide the network with a link gain up to 14 dB traded off with an energy demand up to 30.7% higher.
- The average power offsets of MH network against a SH depend on several parameters
  - The most significant parameter seems to be the ratio between transmit and receive power consumption. This ratio depends on the chipset characteristics.
- Investigation of best sensors locations to optimize the energy consumption within the cooperative topology.
- This work is a first exercise step in assessing reliability and life time trade-off with real-world cooperative ECG systems for body area sensor networks.

THANK YOU

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